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COMPARISON OF EXPERIMENTAL MUNICIPAL REFUSE COLUMN STUDIES WITH LANDFILL FIELD TEST CELLS

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INTRODUCTION

The determination of the impact of municipal refuse disposal on the environment is a very important but complex issue. The use of landfill disposal will continue to be the most accepted means of disposing of municipal refuse. The generation of leachate from these landfill sites will have an impact on the surrounding ground water. Capping the refuse site can reduce the infiltration of moisture and can limit the quantity of leachate generated. However the complete sealing of moisture input and output is neither practicable nor desirable. Therefore to shed light on the mechanisms of leachate generation and composition and to determine the effects of hazardous materials codisposed with municipal refuse, there is a need to conduct basic experimental research. Unfortunately, conducting research in a municipal refuse site is exceedingly difficult and the results are difficult to interpret.

One approach to conducting municipal refuse research has been to use laboratory scale leaching columns packed with municipal refuse. Although the experimentation is relatively easy to perform, the effects of some of the complex interactions found in the field are lost. Large objects (usually metal) must be excluded due to the column size, the municipal refuse must be homogenized, the microbial population growth is seldom established, and the leachate hydrodynamics are not developed in the same way as in the field. As a result, there is difficulty in relating laboratory results to field situations. At present there is no direct means of interpreting laboratory data and actual field behaviour. This difficulty of using laboratory scale leach tests to predict field behaviour raises concerns about the applicability of the Leachate Toxicity Test used to classify the hazardous nature of solid wastes. Clearly, a means of conducting laboratory scale experiments so that field behaviour could be predicted, would be very valuable.

The work presented in this paper represents part of the on-going research into the effects of co-disposal of industrial and municipal wastes. The focus of this paper is on the question of relevance of column study leachate results using municipal refuse to field studies of municipal refuse leachate. The columns used for this study have been in continuous operation for over 1000 days and various aspects of this work have been previously reported [1]. The columns, although relatively large for laboratory scale are small compared with field test cells and present significant advantages over field test cells. The difficulties associated with field test cells are manifest by the few reported experiments in which water throughputs have been measured. The column studies presented in this paper are compared with field study data performed for the U.S. EPA at three different sites in the U.S.A.. These EPA studies provide a limited number of parameters for comparison but can be divided into both small and large field experiments for exploring size effects in municipal refuse test cells. Variability of parameters due to uncontrolled factors such as heterogeneity and environmental conditions require that some data averaging be performed. The techniques for data normalization and averaging are discussed.

EXPERIMENTAL

COLUMN STUDY

The column study[1], supported by the Ontario Ministry of the Environment was designed to simulate field conditions and to investigate the effect of co-disposal of a hazardous solid waste on the municipal refuse environment. There are 16 columns in operation packed with 4 different compositions: 100% municipal solid waste(MSW), MSW + 8% industrial waste(IW), MSW + 30% IW and 8% IW in sand. The high density polyethylene cylindrical columns are 1.93m high, and 0.33m in diameter and contain approximately 43 kg (dry weight) of MSW. One half of the columns receive moisture input from precipitation while the other half receive controlled periodic water additions. The systems are maintained in unsaturated flow conditions with regular leachate removal from the bottom reservoir. Three MSW columns, column number 1,2 and 3, are used in the comparison with small and large field cells. This study is on-going amd the columns have been in continuous operation for over three years.

SMALL FIELD CELLS

The data from two different U.S. EPA small field cell studies are used to compare with the column study.

The Boone county study[2] located in Kentucky, U.S.A., was established to investigate production of leachate from MSW field cells and other environmental effects on leachate generation. Five sanitary landfill cells, one large, one medium and three small field cells, were constructed. Two small field cells, BCFS #2A and BCFS #2B were used in the comparison for this paper. The cells were enclosed in cylindrical steel pipes, 1.83m in diameter and 3.66m high and contained approximately 2,100 kg (dry weight) of municipal refuse. The cells were constructed in August 1972, and the research concluded with the site closure in August 1980.

The Center Hill study[3] located in Cincinnati, Ohio, was established to investigate solid waste decomposition and contaminant release in various types of simulated landfills including the effects of codisposal with industrial wastes. A total of 19 small field cells were constructed in late 1974 and early 1975. Each test cell contained approximately 1,800 kg (dry weight) of municipal refuse. The cell size was identical to the one used in the Boone county study. The C.Hill #4 cell containing MSW only and receiving 813 mm/year of water, was selected for the comparison in this paper. The operation was terminated and cells were disassembled in April 1983.

LARGE FIELD CELLS

The data from two different U.S. EPA large field cell studies are used in the comparison for this paper.

The large field cell data from the Boone county study described above was used. The dimensions of the cell BCFS #1 were 45.4m x 9.2m and contained approximately 286,000 kg (dry weight) of MSW.

The Sonoma County, California[4] study investigated the effect on refuse stabilization of applying excess water, septic tank pumpings and recirculated leachate. A total of five field cells were constructed and monitored for over four years, from late 1971 to early 1976. The test cell Sonoma C used in the comparison for this paper was a control cell approximately 18 meters square by 3m deep. This cell contained approximately 352,000 kg (dry weight) of MSW and was operated similarly to BCFS #1 cell.

CELL DATA

Summarized data for the test cells is presented in Table 1.

TABLE 1. SUMMARY OF TEST CELL DATA

Test cell	Avg. Annual Leachate (l/kg/year)	Refuse Mass Dry Weight (kg)	Max. Refuse Depth (m)	Refuse Dry Density (kg/m3)
FIELD				
BCFS #1	0.57	286,000	2.56	429
SONOMA C	1.91	352,000	2.62	460
SMALL				
BCFS #2A	0.60	2,046	2.56	304
BCFS #2B	0.58	2,113	2.56	314
C. HILL #4	0.99	1,855	2.4	290
COLUMN				
COL #1	1.21	42.9	1.8	299
COL #2	1.21	43.1	1.8	300
COL #3	1.91	42.8	1.8	298

-BCFS #2A,#2B, BCFS #1 .... ref.2
-C.HILL #4 .... ref.3
-SONOMA C ref.4
-COL #1,#2,#3 ....this work

The average annual leachate production per kilogram of dry refuse for the column study varies from 1.22 l/kg for environmental precipitation to 1.91 l/kg for controlled water addition, and is greater than for the small test cells and BCFS #1 field cell,but is smaller than for the Sonoma C field cell. The refuse mass is 47 times smaller than small cells and is approximately 7,400 times smaller than the large field cells. The refuse depth is approximately 1.4 times lower than both small and large field test cells. The packed refuse dry densities for the columns and small field cells were very similar, however, densities were approximately 1.5 times smaller than the large field cells.

COMPARISON PARAMETERS

Many parameters were monitored in the various studies compared, however, only 9 parameters listed in Table 2. were common to most studies.

TABLE 2. LEACHATE PARAMETERS COMPARED

Parameter	BCFS #1	SONOMA C	BCFS #2A, 2B	C. HILL #4	COLUMNS #1, #2, #3
pH	x	-	x	x	x
COD	x	x	x	x	x
Calcium	x	x	x	-	x
Zinc	x	x	x	x	x
Iron	x	x	x	x	x
Manganese	x	-	x	-	x
Magnesium	x	-	x	-	x
Sodium	x	x	x	-	x
Potassium	x	x	x	-	x
Chloride	x	x	x	x	x

RESULTS AND DISCUSSION

Graphical Comparison

The average concentration history and mass removal curves comparing leachate form the column study to both small and large field test cells are presented in Figures 1-11. The concentration or cumulative mass removal has been plotted against cumulative leachate volume rather than time since the leachate concentration trends and subsequent mass removals are more leachate volume related. Leachate volume and mass removal data are also normalized by dividing by the dry weight of the refuse to account for the different sizes of the cells.

The sampling intervals and leachate flow rates for all studies were different and were therefore, normalized by calculating weighted mean concentrations of the leachate parameters at common points in the leachate flow history. This was done by calculating the mass of the parameter (concentration times water volume) that was removed from the refuse between sample analyses over the interval of leachate flow, usually 0.5 l/kg of dry refuse. This mass was then divided by the volume of leachate to give a weighted mean concentration for the leachate volume interval. Cumulative mass removals were obtained by adding the incremental masses used in calculating the weighted mean concentrations.

pH

The variation of pH is shown as a function of leachate volume in Figure 1. The upper and lower lines drawn in the figure are the +/- 1 standard deviation values of the mean pH values of the leachate for the column and small test cell experiments. There is clearly a significant variation of pH within these studies. Only one of the large field test cells had reported pH values and the variability of these data were as great as in the smaller scale studies.

COD

The variation of COD as a function of leachate volume is shown in Figure 2. The upper and lower lines drawn in the figure are the +/- 1 standard deviation values of the weighted mean concentrations for the column and small test cell experiments. The upper and lower values for the large test cells are the upper and lower weighted mean concentrations for the two large scale experiments. For the COD data there is a clear trend of higher initial values for smaller scale experiments. This distinction is lost after 2 l/kg leachate have been generated.

The initial difference between the small and large scale experiments is also reflected by the total mass removal of COD as shown in Figure 3. The column and small field cells appear to be able to release significantly more COD per mass of refuse than the large field cells. However, this difference is primarily due to the initial concentration differences in the first 1 to 2 l/kg of leachate produced.

Zn,Mn

The variation of concentration of Zn and Mn as a function of leachate volume is shown in Figures 4 and 5 respectively.For these elements, the trend is for the larger scale experiments to show higher initial values. After approximately 1 l/kg leachate has been generated the concentration profiles overlap.

Ca,Cl,Mg,K,Na

The variation of concentration of Ca,Cl,Mg,K,and Na as a function leachate volume is shown in Figures 6,7,8,9 and 10 respectively. These elements have been grouped because there is a trend for the initial concentrations to be higher for the smaller scale experiments. After approximately 1 to 2 l/kg of leachate has been generated the concentration profiles overlap.

Fe

The variation of concentration of Fe as a function of leachate volume is shown in Figure 11. The iron concentration history is unlike that of other elements because of the relative constant concentration after the initial 1 l/kg of leachate. The three different experimental scales show remarkably similar concentration histories.

From the concentration profiles of the elements studied there appears to be a greater tendency overall for the smaller scale experiments to show higher initial concentrations. This behaviour might be associated with the packing density or shredding carried out in the small scale studies. There is better agreement between the small field cells and the column studies, which have similar packing conditions, than with the large field cells. This association with packing density is tenuous since not all elements are similarly affected. Indeed the similarities of the leachate concentrations from all the experimental measurements are more striking than are the differences.The leaching behaviour was modelled with first order kinetics for each of the elements.

$$C(V) = C^{o}\exp(kV)$$

The concentrations modelled were the weighted mean concentrations and the time function used was the normalized leachate volume l/kg (see Table 3). The C^{o} value is the least squares fitted concentration at 0 leachate. Average regression correlation coefficients, r, of greater than 0.99 were found for the column studies, greater than 0.97 for the small field test cells, and greater than 0.94 for the large field test cells. The exception for all the studies was the iron behaviour. The iron concentration is clearly not first order with time or leachate volume, nor do the concentrations vary with pH change as has been suggested in the literature. The source of the constant iron concentration is most likely the ferrous waste in the municipal refuse but the leaching mechanism is not yet established. The only other element to have a weak

correlation coefficient with first order kinetics was chloride in the large field test cells. The poor correlation was the result of an apparent increase in chloride concentration with time in the one of the large field cells (Sonoma C).

The similarities in leaching behaviour for the three experimental scales, included the degree of data fit to first order kinetics and the concentration values of all the species studied after the initial period of 1.5 to 2 l/kg of leachate. Even the iron concentration profiles which do not conform to the kinetic model are very similar for the three experimental sizes The concentration normalization used did not eliminate the generally higher initial concentrations found in the smaller scale experiments. The values of the parameters used to fit the first order kinetics shown in Table 3 demonstrate the variability between the three experimental scales.

TABLE 3. EQUATION CONSTANTS FOR $C=C^{0}EXP(kV)$

PARAMETER	COLUMN STUDY			SMALL CELLS			LARGE CELLS		
	C^0	RATE	r	C^0	RATE	r	C^0	RATE	r
COD	89	-.77	.982	57	-.46	.983	38	-.52	.992
CALCIUM	5.1	-.73	.991	2.25	-.47	.987	1.65	-.43	.976
ZINC	0.11	-.83	.984	0.16	-.97	.971	0.13	-1.45	.909
IRON	0.67	-.08	.311	0.63	-.05	.316	0.54	-.21	.699
SODIUM	3.83	-1.12	.992	1.57	-.94	.979	1.05	-.59	.994
POTASSIUM	2.59	-1.19	.983	2.19	-.95	.993	0.89	-.58	.987
CHLORIDE	5.06	-1.43	.989	1.39	-.82	.926	0.93	-.30	.704
MANGANESE	0.09	-.73	.985	0.05	-.54	.949	0.11	-.75	.989
MAGNESIUM	0.77	-.92	.988	0.49	-.73	1.0	0.41	-.66	.987

C^0 fitted initial weighted mean concentration g/l
RATE rate constant k
V cumulative leachate volume l/kg dry refuse
r regression correlation coefficient

CONCLUSIONS

1 A first order rate equation is suitable for modelling concentration profiles in leachate from column studies to large scale field studies of municipal refuse. The exception, found from the elements studied, was iron. The significant amount of iron waste in municipal refuse leads to a relatively constant concentration over the period studied.

2 The normalization of the time scale through the use of the leachate volume produced per mass of refuse, and the use of weighted mean concentrations are very effective in comparing data from different studies and scales of studies.

3 After the first 1 to 2 l/kg of leachate, the modelled column data could be used to predict field behaviour to a least 4.5 l/kg of leachate. The extent of the model validity will be further assessed as the study progresses.

4 An increase in the scale of the study of municipal refuse leachate generation does not directly lead to increases or decreases in leachate contaminants though for the limited number of elements that were available for comparison more were found to be less concentrated with the larger scale experiments.

5 The column studies used in this work appear to provide a very good means for relating the effects of codisposal parameters to field behaviour.

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FIG. 1 LEACHATE PH

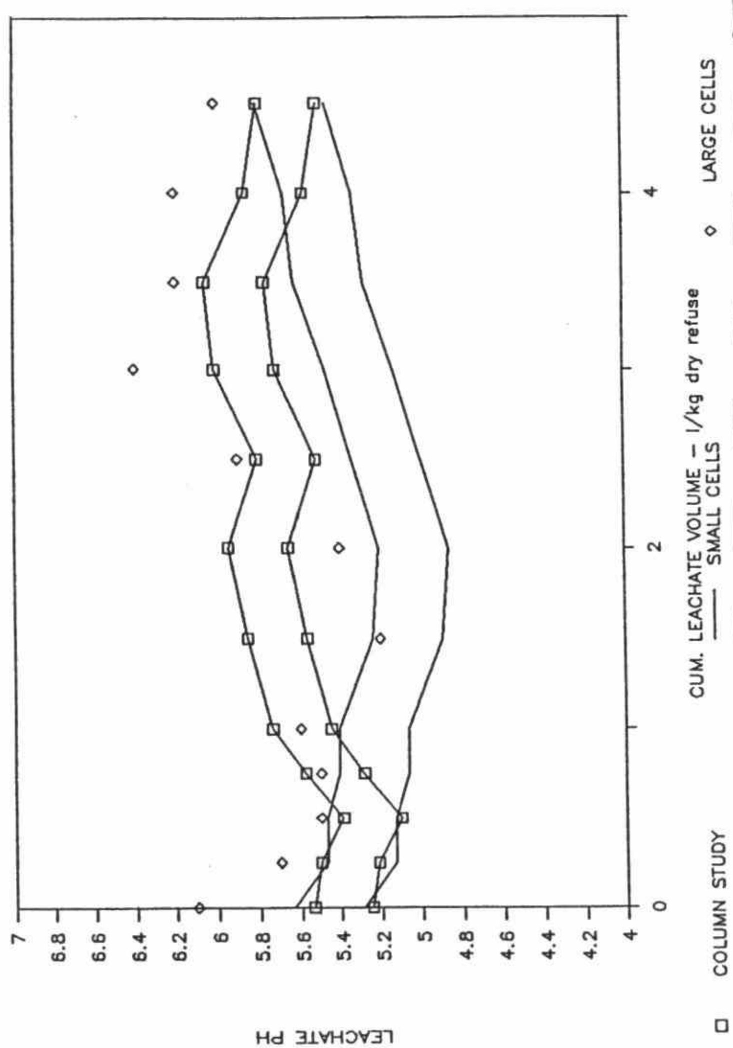

FIG. 2 COD CONCENTRATION HISTORY

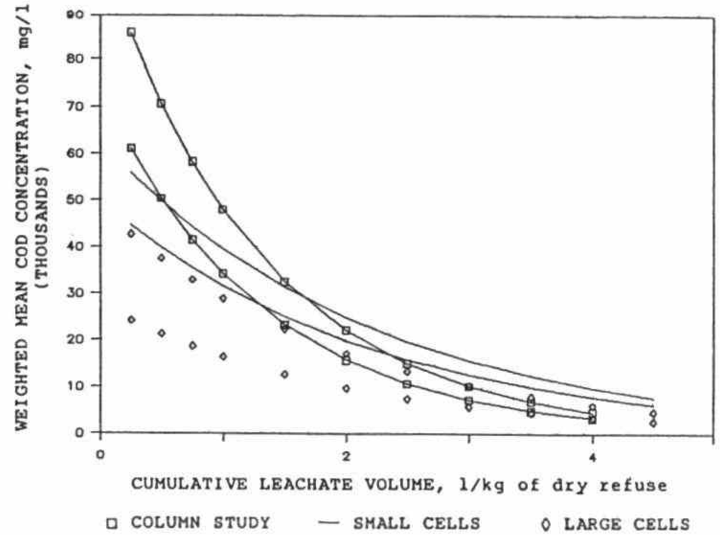

FIG. 3 COD MASS REMOVAL

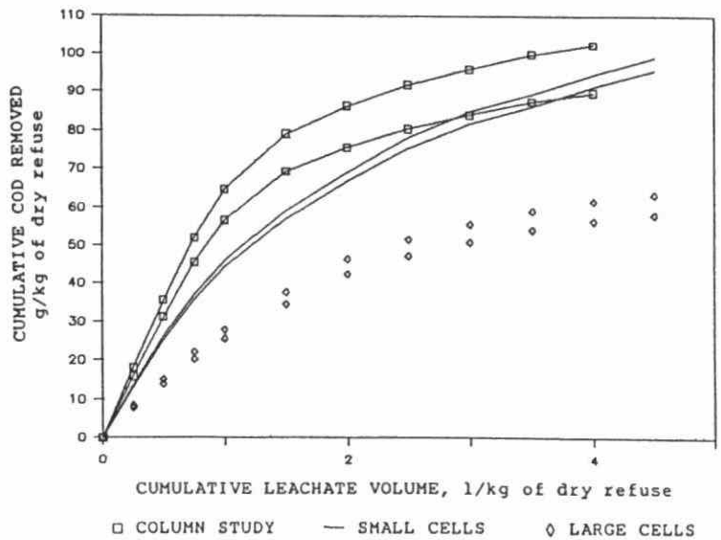

FIG. 4 ZINC CONCENTRATION HISTORY

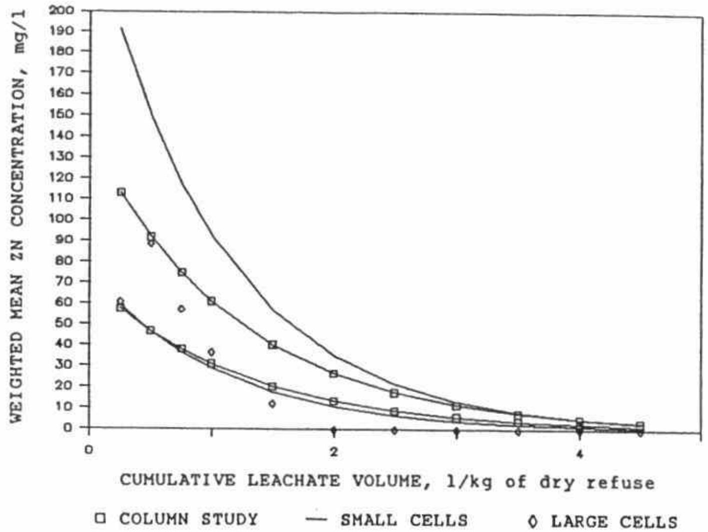

FIG. 5 MANGANESE CONCENTRATION HISTORY

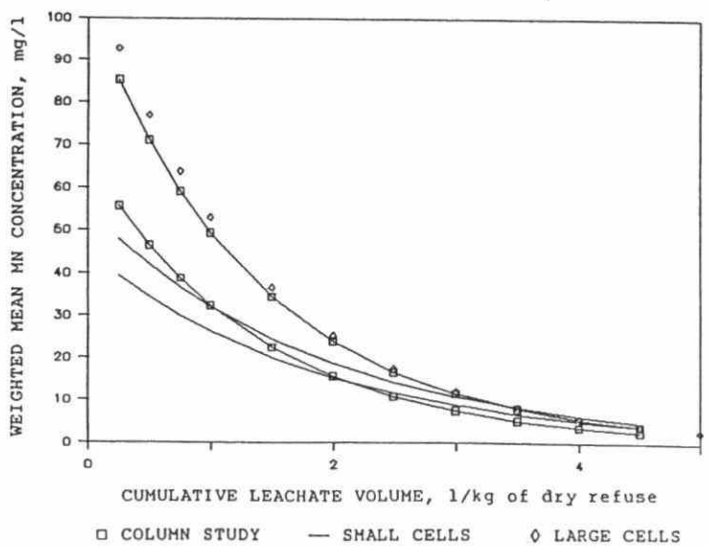

FIG. 6 CALCIUM CONCENTRATION HISTORY

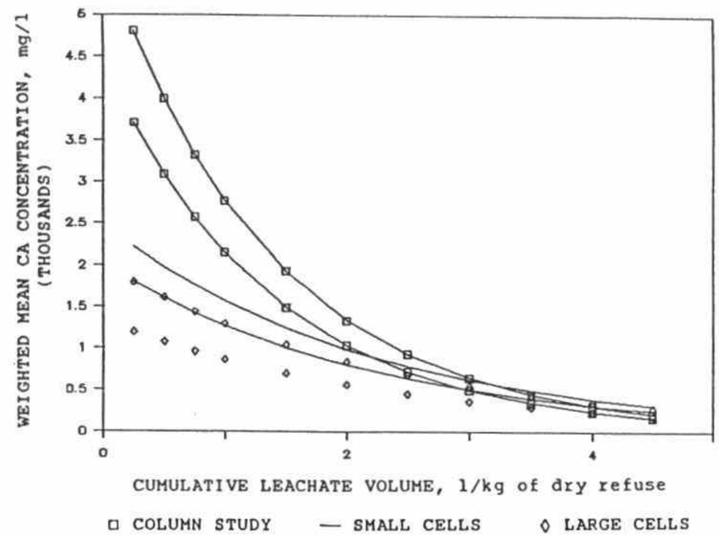

FIG. 7 CHLORIDE CONCENTRATION HISTORY

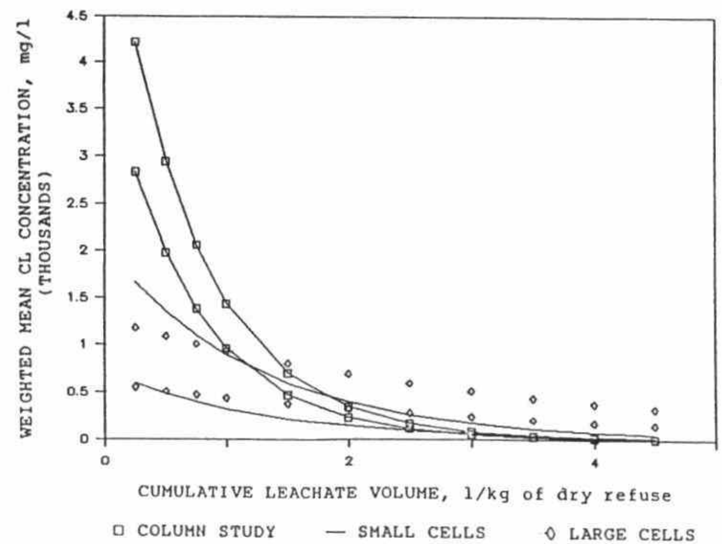

FIG. 8 MAGNESIUM CONCENTRATION HISTORY

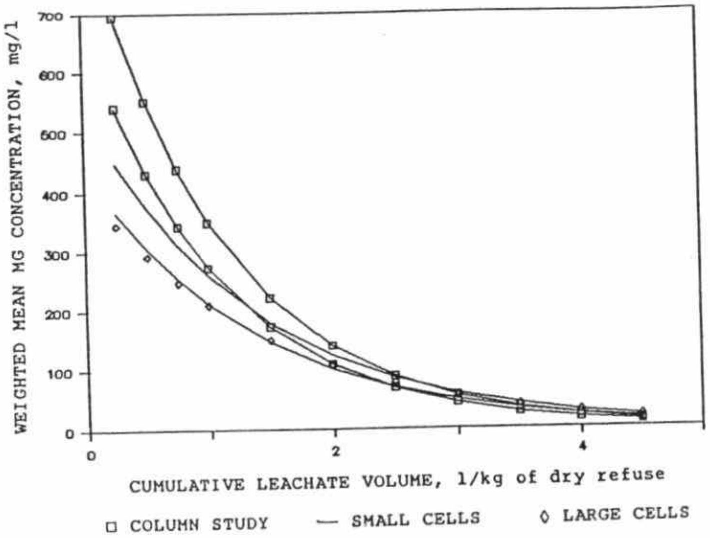

FIG. 9 POTASSIUM CONCENTRATION HISTORY

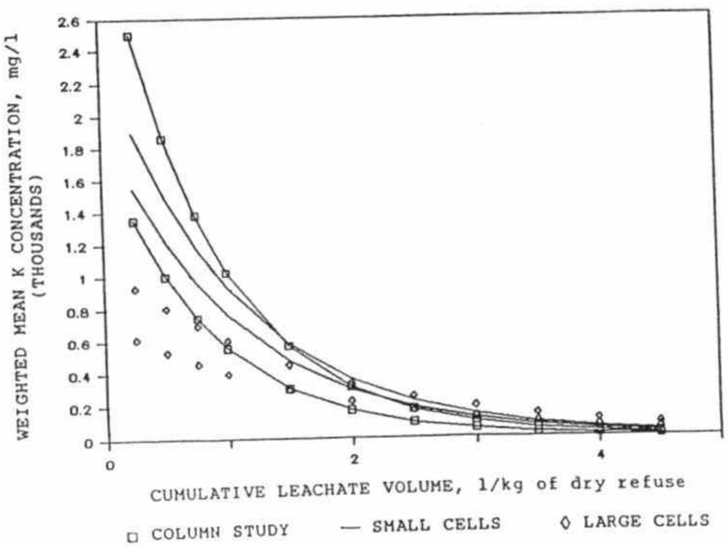

FIG. 10 SODIUM CONCENTRATION HISTORY

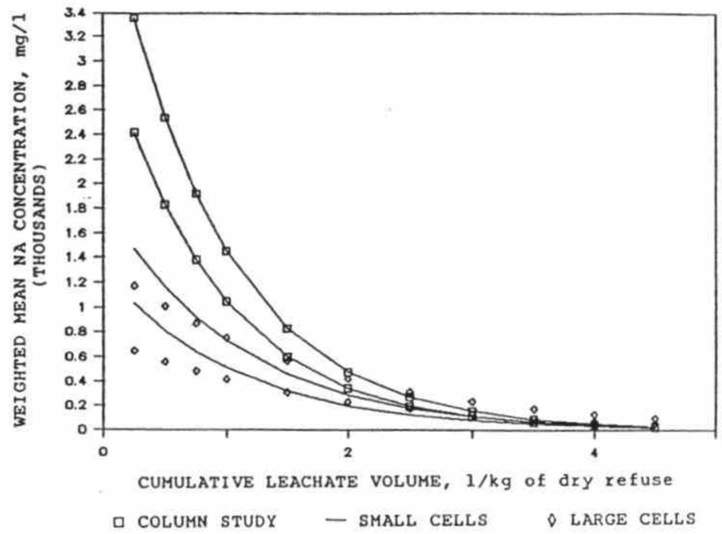

FIG. 11 IRON CONCENTRATION HISTORY